Building Research Establishment Digest

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Condensation in roofs

Although most roofs perform well, problems of condensation are increasing. The risk is greatest in roofs that have impermeable sheet coverings, and flat roofs in particular have frequently given rise to problems. With newer forms of construction, lower roof pitches, and changes in standards and forms of heating, similar problems are now being met in pitched roofs.

This digest discusses design principles for minimising the risk of condensation and consequential damage to decorations or structure.

Design principles

The simplest roof is no more than a rain shield but many designs include a lining or a ceiling, separated from the rain shield or cladding by an air space and insulation. If warm moist air from the building can enter the air space, it will condense on any surface whose temperature is below its dewpoint. This is most likely to be the underside of the cladding, from which moisture can drip on to the ceiling or damage the roof structure. The design should therefore aim to balance temperatures and humidities so that the surface temperatures of critical component parts of the roof remain above the dewpoint of the surrounding air for most of the time. Practical measures that can be taken are:

a provide a vapour barrier at the warm side of the roof structure to prevent the entry of moisture from the building.
b provide a rain shield that is permeable to water vapour, to allow for the transfer of moisture to the outside.
c ventilate the roof space to the outside air.
d blow 'dry' air into the roof space under pressure and thus prevent moist air from entering it.

The practical difficulties of achieving these measures vary from one type of roof to another, and methods appropriate to different roof types are discussed later. For instance, it is very much easier to achieve a permeable rain shield on a pitched roof than on a flat one; it is also easier to form an impermeable membrane above a flat roof deck than below it.

Digest 110 *Condensation* sets out procedures for steady-state calculation of internal temperatures and dewpoints in roofs which do not incorporate ventilated air spaces, and these procedures enable the risk of steady deposition to be assessed for lightweight (low thermal capacity) roofs. An estimate has to be made of the most adverse external and internal temperatures and humidities that will occur at any time.

Such calculations cannot be made for heavyweight (high thermal capacity) roofs such as concrete roofs, which take some time to warm up and cool down, but it is possible to assess whether a steady deposition in concrete roofs is likely by making steady-state calculations based on the most adverse *daily mean* temperatures and humidities.

It is not generally possible to calculate with certainty the risk of condensation in roofs with ventilated air spaces.

Even if there is no steady deposition of water, intermittent condensation can occur. If the roof incorporates absorbent materials that are unaffected by moisture, small amounts of moisture may be deposited for short periods and can later evaporate without causing trouble. Care must be taken to avoid situations where water might drain to where it can cause damage and the ventilation must be good enough to encourage drying during favourable atmospheric conditions.

Condensation is not necessarily troublesome; on the upper side of underfiling felt it is usually harmless as it can normally drain away, but on the underside it is likely to cause trouble either by dripping on to the ceiling below or by draining to a point where it can wet the structure.

Particular attention has to be paid to the possibility of condensation on cellulosic materials such as flaxboard, strawboard, fibreboard or chipboard, which permanently lose mechanical strength or rot when they become wet. Untreated timber is susceptible to fungal attack when its moisture content exceeds 20 per cent by weight. Where there is any risk that it might reach this condition, it should be pressure impregnated with preservative, but timber that has been treated with preservation salts may, when it gets wet, cause corrosion of metal fastenings.

Types of roof

Various forms of roof are now discussed to bring out the factors affecting condensation. The order of presentation is not related to the frequency of occurrence of the roofs, but is chosen to illustrate the principles in a convenient manner.

Sheeted roofs (Fig 1)

Sheeted roofs, which are commonly used in factories, consist of an outer cladding of, say, corrugated metal or asbestos-cement and an inner lining, often fibreboard or plasterboard, with an air space between cladding and lining which may incorporate some additional thermal insulation. In adverse conditions, moisture can enter the air space from the building through gaps between the lining boards or by diffusion through the lining itself, condense on the underside of the cladding and drip on to the insulation or the lining. The problem is reduced if air can flow through gaps between the cladding sheets; spacers can sometimes be used to increase the size of the gaps. Ventilation of the air space can reduce the moisture content of the air within it, and hence the risk of condensation and dripping; it also promotes drying during favourable conditions.

Though sheeted roofs with ventilated air spaces are suitable for most factories, there can be problems in factories where high humidities occur, eg breweries, dye-houses, etc. These can sometimes be overcome by providing a vapour check at the inside of the structure. The best available method of forming a vapour barrier at ceiling level is to spray the underside of the lining with a suitable plastics coating. This treatment is, however, expensive and the film might be ruptured by roof movements. Nevertheless, some form of vapour barrier should be provided as it will reduce the amount of water vapour entering the roof.

Lightweight flat roofs (Fig 2)

Lightweight flat roofs comprise a waterproof membrane covering a structural deck, an air space and a lining or ceiling; they may also incorporate insulation. The air space cannot be ventilated through gaps in the cladding, neither can water vapour diffuse through the waterproof covering which is usually bitumen felt, asphalt or sheet metal. Moist air which finds its way into the air space therefore condenses on a metal deck, or diffuses through a timber roof deck, wetting the deck and condensing on the underside of the waterproof covering. The condensation risk depends on the roof design and because of this all timber used in flat roofs should be pressure impregnated with preservative.

Cold roof In the roof illustrated in Fig 2a, the insulation is placed on top of the plasterboard; this will prevent surface condensation on the ceiling but there is a risk of condensation on the underside of the waterproof covering. This type of construction is commonly referred to as a 'cold' roof, because for much of the year the temperature of the air within the roof space is lower than the temperature inside the building. The amount of water vapour entering the roof structure can be restricted by a vapour check, eg sheet polythene at ceiling level.

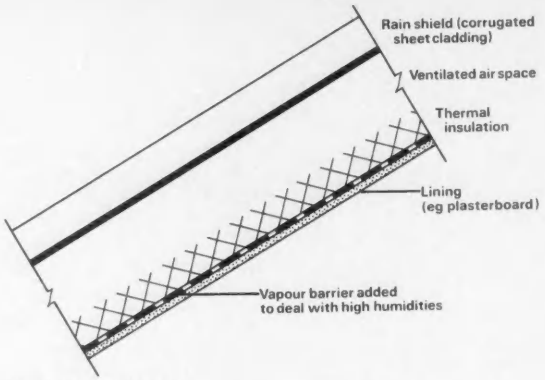
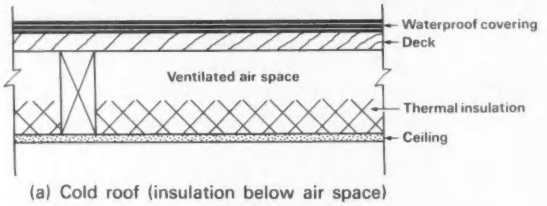

Rain shield (corrugated sheet cladding)
Ventilated air space
Thermal insulation
Lining (eg plasterboard)
Vapour barrier added to deal with high humidities

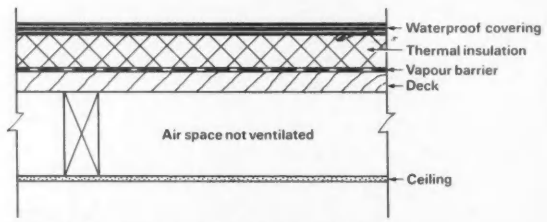
Fig 1 Sheeted roofs

The only way in which the air spaces in a lightweight flat roof can be ventilated is through gaps or grilles at each end of every air space but there is a fairly high resistance to the flow of air in these long narrow air spaces, particularly if they are partially obstructed by stiffeners. If the roof overhangs the external walls, ventilation openings can be provided in the soffit but if the roof finishes flush with the external walls, grilles have to be built into the walls. Neither the air flow through the roof spaces nor the moisture flow into the roof can be estimated with any accuracy. Furthermore, if water is trapped between the timber deck and the waterproof covering, one cannot rely on this being removed by evaporation. Experience has shown that there is a relatively high risk of condensation in this type of roof.

Warm roof (Fig 2b) The behaviour of a lightweight flat roof in respect of condensation is improved if the insulation is placed above the deck and a vapour barrier added between the deck and



(a) Cold roof (insulation below air space)



(b) Warm roof (insulation above air space)

Fig 2 Lightweight flat roofs

the insulation. The air in the deck spaces is warmer than the outside air and this type of roof is commonly referred to as a 'warm' roof. In this form of construction with overdeck insulation, no attempt is made to ventilate the roof spaces. If the temperature of the vapour barrier is kept above the dewpoint of the air, condensation will not occur within the roof structure. When it is possible to specify the most adverse temperatures and humidities both inside and outside, the amount of insulation required above the vapour barrier can be calculated.

In housing, the internal conditions are not known but experience has shown that if the roof insulation meets the requirements of the Building Regulations, with most of it located above the vapour barrier, the risk of condensation within the structure is small.

The vapour barrier normally consists of bitumen felt (not less than 13 kg/10 m^2) well lapped at joints and nailed or spot bonded to the structural deck in compliance with BS CP 144. An all-over coat of hot bitumen mopped on to the top of the bitumen felt completes the vapour barrier and also provides a means of sticking down the thermal insulation. With this form of construction it is essential that the insulation is kept dry. The insulation boards must also be closely butted since there is a high risk that coverings like bitumen felt or asphalt will fail over gaps. At the perimeter of the roof the vapour barrier must be turned up and sealed to the rain shield to prevent ingress of moisture at the edges of the insulation boards. Similar measures are needed at any breaks in the roof such as at roof lights, around pipes, etc. On large roofs it is also advisable to divide the insulation into sealed compartments.

Lightweight pitched roofs (Fig 3)

Lightweight pitched roofs can be constructed in a similar way to lightweight flat roofs, with a sloping waterproofed deck, a ventilated roof space and a ceiling. Fig 3 illustrates a typical construction with a timber deck and insulation between joists. The roof space can be ventilated by suitable openings at eaves or gables.

The roof illustrated in Fig 3 is a 'cold' roof; the insulation is at ceiling level and the roof space is cold. As with the similar flat roof there is a high risk of condensation on the underside of the water-proof covering. It is more satisfactory to fix the insulation on the slope of the roof, as in the 'warm' flat roof. There is then little risk of condensation if a vapour barrier is placed below the insulation.

Tiled or slated roofs (Fig 4)

The tiles or slates of traditional pitched roofs were often laid only on battens on rafters, or fixed direct to timber sarking, so that the roof space was freely ventilated through gaps between the tiles or slates. It is now usual to provide an underlay to the tiles or slates, usually of bitumen felt. If the underlay is permeable, either because it is not saturated with bitumen or because of gaps at the lapped joints, there is still very little risk of trouble from condensation. Moist air which enters the roof space can escape through the permeable covering, and any intermittent condensation in the roof is absorbed by the timber or felt and later re evaporated. If timber sarking is used above the rafters it provides further absorbent material.

However, impermeable materials such as saturated bitumen felt, PVC and polythene are now extensively used for underlays. These reduce the rate at which moist air can escape from the roof space so that condensation problems are becoming more common. Water condensing on the underside of an impermeable underlay may drip on to the ceiling or drain down the roof slope, wetting timbers at the eaves and causing damage to the structure. If timber, chipboard or other organic material used as sarking has an impermeable underlay above it, the

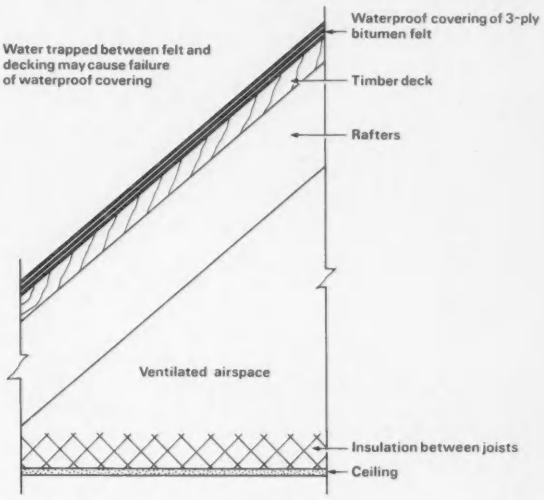


Fig 3 Lightweight pitched roof ('cold')

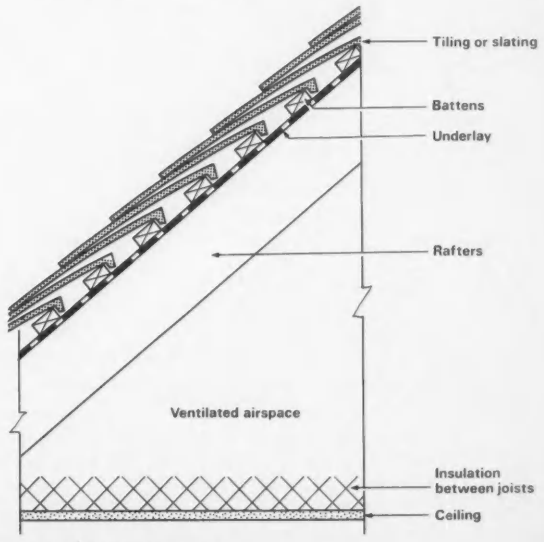


Fig 4 Tiled or slated roof

sarking material may be damaged by condensation; this could usually be avoided by substituting a 'breather' felt for the impermeable underlay and ventilating the roof space.

Concrete roofs

Concrete, either cast in situ or precast, can be used as a structural deck. A lightweight screed is sometimes used to provide falls (though these are better formed in the structural deck) and additional insulation. The deck is usually covered with an impermeable waterproof covering, such as bitumen felt or asphalt.

In wet districts it is not easy to dry out the construction water or to prevent further wetting before the waterproof covering is laid. Moisture can diffuse through the concrete or any cracks in it and condense on the underside of the waterproof covering. Condensed water may flow between the waterproof covering and the concrete to drip down through joints or cracks in the concrete deck. The condensed water may also saturate any insulating screed, thus greatly reducing its value as insulation. These roofs can, nevertheless, perform satisfactorily if the concrete is dry before they are covered and if the internal humidity in the building is low.

The waterproof covering may also be damaged by blisters caused by vaporisation of water entrapped below it. Properly designed breather vents, in conjunction with a pressure-releasing layer beneath the rain shield, can overcome this problem but they are not very effective in preventing trouble from condensation.

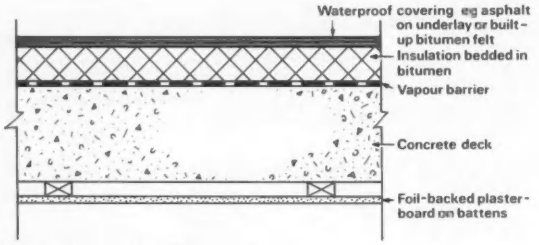

Waterproof covering eg asphalt on underlay or built-up bitumen felt
Insulation bedded in bitumen
Vapour barrier
Concrete deck
Foil-backed plasterboard on battens

Fig 5 Conventional concrete roof

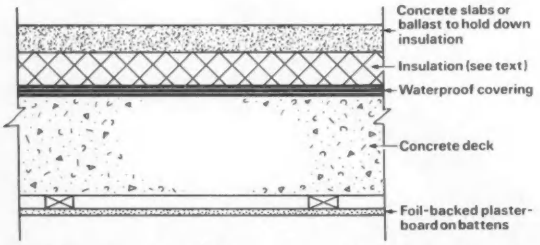


Fig 6 'Inverted' roof (waterproof covering *below* insulation)

An effective method of avoiding condensation, at least in continuously heated buildings, is to provide overdeck insulation as shown in Fig 5. There may be some temporary condensation on the underside of such concrete roofs in intermittently heated buildings, but this can usually be avoided by using a lightweight battened out ceiling, preferably using foil-backed plasterboard, to avoid staining during the drying-out period.

The 'inverted roof' (Fig 6) operates on the same principle as overdeck insulation but uses materials that are unaffected by moisture, such as foamed glass or extruded polystyrene, above the waterproof covering. The insulation is not covered with a waterproof layer as with overdeck insulation, but simply weighted down by gravel of a suitable size or concrete paving slabs.

Pressurised roof space

A suspended ceiling may be used to provide a roof space to accommodate machinery, or for appearance, or for acoustic absorption (Fig 7). This introduces an air space which must be taken into account in assessing the condensation risk. For instance, the thermal insulation of an acoustic ceiling may be high enough to reduce temperatures within the structure below the dewpoint of the air within the building.

In such cases, warm 'dry' air can be blown into the roof space to ensure that the dewpoint of the air within it is kept below the temperature of any part of the structure. The air pressure in the roof space has to be high enough to prevent the entry of water vapour from the building, and to ensure a downward flow of air through gaps. It is desirable to incorporate a vapour check at ceiling level to reduce the diffusion of water vapour into the roof space and to reduce the gaps through which air is lost. The excess pressure can then be kept to a minimum, to save on the cost of fans and energy.

This technique is normally justifiable only for buildings with abnormally high internal humidities, such as swimming pools.

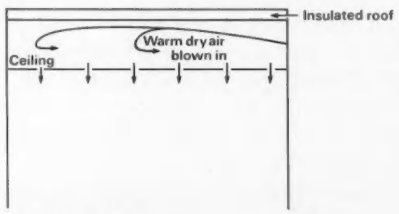


Fig 7 Pressurised roof space

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